HIGH TEMPERATURE THERMOCOUPLE
RESEARCH AND DEVELOPMENT PROGRAM

MONTHLY PROGRESS REPORT NUMBER 1
Period 17 June 1963 to 1 July 1963
Contract Number NAS 8-5438
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prepared for
GEORGE C. MARSHALL SPACE FLIGHT CENTER
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work performed by
AUTO-CONTROL LABORATORIES, INC.
5251 West Imperial Highway
Los Angeles 45, California

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Prepared By: R. L. [signature] Jr.
Section Head, Environmental Components

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ABSTRACT

This report covers the period 17 June 1963 to 1 July 1963, under Contract NAS 8-5438, which calls for twelve months of research and development of a high temperature thermocouple capable of measuring rocket engine exhaust temperatures in the 3000°C temperature range, under adverse conditions of oxidation, erosion, vibration, and shock. The current period was utilized in project organization, and preliminary investigation of design parameters necessary to development of the first of three sets of four gauges, to be delivered at four month intervals.

The primary objectives of the program are to advance the state of the art of high temperature thermometry, and to develop an end product suitable for in-flight temperature measurements on the SATURN vehicle.

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SECTION I

SUMMARY

1.0 Period Covered

This report covers the period 17 June 1963, the date of Contract No. NAS 8-5438, to 1 July 1963, the beginning of the following calendar month.

1.1 Statement of Work

The Contractor shall advance the state-of-the-art of high temperature thermometry and specifically improve the technique of accurately measuring high temperatures by designing, fabricating, testing, and delivering nine (9) thermocouple probes capable of operation in the 3000°C temperature range under adverse conditions of erosion, oxidations and high stress levels for useful periods of time. Also, present methods of thermocouple probe fabrication will be modified such that the end product will be suitable for in-flight temperature measurements on the SATURN vehicle.

To accomplish the above objectives, the Contractor shall consider and explore specific R&D efforts as follows:

a. Development of the physical structure of an immersed probe to attain minimum drag and highest resistance to bending and shear forces.

b. Ascertain the best combination of ingredients in the protective coating of the probe to extend the term of oxidation resistance.

c. Determine the best combination of compensated lead wires for use with immersion type probes.

d. Incorporate latest state-of-the-art materials as potting and sealing elements in the base of the probe.

1.1 Statement of Work Cont...

e. Determine effects of reactions between oxide coatings and tungsten in relation to the emf output.

f. Establishment of rates of erosion for different types of refractory coatings such as tungsten disilicide, carbides and cermets when subjected to high velocity, high temperature gas streams.

1.2 Progress

Accomplished during the current reporting interval were:

a. Conference with Mr. Harlan Burke on 17 June 1963.

b. A preliminary analysis of a hypothetical mach regime in the temperature range 500°C to 3000°C.

c. Start of investigations into oxidation resistant coatings for use in high temperature, oxidizing gases.

d. Project organization and establishment of a report format to be used during this project.

e. Arrangement for visit to NASA, Huntsville on 24 July 1963.

f. Selection of a tentative measuring technique for yielding useful information concerning the oxidation rate of probes, unless such information is available from NASA.

g. Selection of possible configurations for the first set of four gauges to be delivered to NASA for test and evaluation on 17 October 1963, and selection of design parameters which require definition by NASA before fabrication of the gauges can begin.

h. Preparation of a set of objectives for the first four month period of the contract.

SECTION II

PAST PROGRESS

2.0 Since this report covers the first period of activity under the contract, there is no progress to report prior to 17 June 1963.

SECTION III

CURRENT PROGRESS

3.0 General

The current reporting period was devoted principally to investigations prerequisite to selection of a design approach for the first group of four gauges to be delivered under the contract.

3.1 Objectives

3.2 Form

The attitude of the gauge relative to flow is important to the designer, when the performance objectives of life, response, resistance to oxidation, erosion, shock, vibration, and loads caused by immersion in the flow are considered.

There are essentially three conditions of attitude relative to flow to be considered:

a. With the gauge mounted transverse to flow, and with flow impingement normal to the longitudinal centerline of the gauge.

b. With the gauge mounted such that flow is parallel to the longitudinal centerline of the gauge, with the medium impinging on its tip.

c. With the gauge mounted such that the flow is turbulent, stagnated, or with unpredictable flow vectors.

3.2.1 Transverse or Parallel Mounting

If it develops that the gauges will be mounted in a medium with a well-established and defined flow pattern, it follows that attainment of the different design objectives will be affected as described in the following paragraphs.

3.2.1.1 Discussion

If the gauge is mounted either transverse to flow, or parallel to flow, response to a step-function change of temperature will be inversely related to the mass velocity seen in the region of the junction. Response is also a function of the mass of the tip structure and the junction, as well as the diffusivity of the materials. Thus, the most favorable conditions for fast response are those of high velocity, low mass in the gauge tip, and good thermal transfer characteristics of the materials. If, conversely, the gauge is mounted in a region where there is no flow, or very low flow, response is predicated upon the mass of the junction and its structure, and the thermal characteristics of the materials. Thus, the designer is on the horns of a dilemma if he is faced with the requirement of designing a probe to satisfy both general requirements: i.e no flow, and high mass velocity. In addition, he is further faced with another dilemma, in that he can not extend the life of the gauge by employing a structure of high mass in a high mass velocity flow, if he is to meet the fast response requirement in a no-flow condition. A low-mass structure, with fast response under no-flow, simply does not lend itself to immersion in a high mass velocity medium because of the accelerated effects of erosion and oxidation.

There is, additionally, the requirement of resistance to the effects of vibration and shock to be considered. The desirable structure would have a small cantilever, with decreasing mass from the base to the tip, a natural frequency of the basic structure outside the vibration spectrum to be encountered, and high internal damping.

3.2.1.1 Discussion Cont...

For resistance to bending and shear forces developed during exposure to high velocity flows, the immersed portion of the gauge should have a geometry which incorporates low drag characteristics over a wide range of mach numbers, from subsonic to supersonic. Since the local velocity of sound in a given medium is related only to temperature, a preliminary investigation of the mach numbers likely to be encountered was made, and is presented in Appendix "A". Suggested cross-sectional shapes suitable for immersion in the flow are the double wedge, single wedge, and biconvex. It is felt that further exploration of this consideration should be withheld until after a general discussion is held with NASA technical personnel to resolve specific questions concerning the installation and the medium.

3.2.2 No-Flow Considerations

It is apparent that the response of the gauge will have to meet certain minimum requirements. Under no-flow, or unpredictably turbulent conditions, designing for fast response presents an entirely different set of problems. As was stated in Para. 3.2.1.1 above, it is felt that this area should be discussed with NASA personnel before proceeding.

3.3 Oxidation Resistant Coatings

The oxidation resistant coatings employed in previous types of gauges may be grouped in three distinct categories:

a. Plasma sprayed coatings.

b. Diffused coatings.

c. Intumescent coatings.

3.3.1 Plasma Sprayed Coatings

Various plasma sprayed high temperature oxides have been given a great deal of testing in the past, under operating conditions very similar to those anticipated in this program. They have been

3.3.1 Plasma Sprayed Coatings Cont...

successful except that they all have a characteristic of chipping due to erosion and thermal stresses. Additionally, their presence has been determined as being contributary to poor response. Upon exposure of the substrate, failure has been quite rapid. Therefore, such coatings are presently regarded as not suitable for this project.

3.3.2 Diffused Coatings

In the ACL Type 4734 gauges, tungsten disilicide, boron nitride, and other silicon compounds were applied to the tungsten sheaths by either gaseous diffusion, or by the pack process. These coatings have apparently retarded the severe oxidation normally seen in tungsten exposed to highly oxidizing, high temperature media. In researching these coatings, there is early indication that another group of materials, the zirconates, may offer some advantages. A more complete discussion of these coatings will be included in the next report.

3.3.3 Intumescent Coatings

This group of coatings have demonstrated an ability to withstand exposure to the required severe conditions of use for protracted periods of time. They are, however, difficult to apply uniformly and tend to thermally insulate the structure by virtue of surface charring. More information concerning some possible uses in this program will be included in the next report.

3.4 Electrical Insulation

As of the date of this report, no new information as regards a type of electrical insulation for use at high temperature has been discovered.

One report, concerning Samarium oxide, was translated from a report written in Germany. Results of this investigation were negative in that the material exhibited a melting temperature lower than Beryllium oxide.

3.4 Electrical Insulation Cont...

Investigations will continue in this area, and results will be presented in succeeding reports.

SECTION IV

PROGRAM FOR NEXT INTERVAL

4.0 Objectives for the interval 1 July 1963 to 1 August 1963 will include the following:

a. Develop and select a suitable form for the immersed portion of the first three prototype gauges.

b. Visit NASA, Huntsville, to discuss details of the gauge installation, and available background data with responsible NASA technical personnel.

c. In conjunction with NASA personnel, review the overall objectives of the project and establish milestones and schedules for their accomplishment.

d. Continue investigations into electrical insulation, directed toward:

(1.) The possibility of developing an optimim depth of insulation.

(2.) Research for an insulator capable of operation at temperatures higher than 2480°C.

(3.) Investigate the possibility of developing a configuration requiring no insulation.

e. Review results of tests performed by NASA on ACL Type 4734 gauges.

(1.) Compare results of each individual test run with serial numbers on gauges. Check against internal construction analyze results.

(2.) Prepare family of tungsten test samples and investigate oxidation resistance.

4.0 Cont...

f. Begin investigations into physical strength of selected gauge configurations.

   (1.) Resistance to bending.

   (2.) Resistance to shear.

   (3.) Resistance to vibration.

   (4.) Resistance to shock.

   (5.) On basis of above, choose a configuration for first four gauges.

g. Start development of a base and mounting configuration.

h. Start investigations of Compensated Lead Wire.

SECTION V

STATEMENT OF MAN-HOURS

5.0 Hours by Category

The expenditure of man-hours during the reporting period, and a recapitulation is presented in tabular form below.

Category	Previous Period	Current Period	To Date
Engineering	0	62.5	62.5
Clerical	0	4.0	4.0
Fabrication	0	0	0
Consulting	0	0	0
Drafting	0	0	0

APPENDIX "A"

THE FREE-STANDING SHAPE VS. FLOW

1. GENERAL

It is felt, at this stage of the program, that the geometry of the immersed portion of the probe will very heavily influence the internal design features because of physical spacing available. Therefore, a preliminary investigation of free-standing shapes for the flow field was started. Results of this investigation are given below.

a. Mach Numbers in the Flow

The $\frac{Cp}{Cv}$ of the medium is not presently known. Moreover, it is not known how $\frac{Cp}{Cv}$ will vary, with time and temperature. Therefore, values of M were calculated for $\frac{Cp}{Cv}$ from 1.0 to 1.5, Absolute Temperatures from 773°C to 3273°C, and local velocities of 1000 to 5000 feet per second.

Local speed of sound was calculated with the following relationship; which gives exact values.

$$a^2 = \gamma RT$$

Where:

a = local speed of sound, feet per second

γ = ratio of specific heats, $\frac{Cp}{Cv}$ dimensionless

R = universal gas constant, dimensionless

T_A = temperature, °C absolute

Mach numbers for M = V/a at discrete values of T, and V were then calculated, and the data was plotted as a complex graph, (See Figure 1) from which could be taken the local Mach number for any

a. Mach Numbers in the Flow Cont...

combination of parameters given above. It is seen, from the graph of Figure 1, that if the extremes of conditions within the total envelope of the values selected for calculation were encountered, the local Mach number could vary from M = 3.25 at $\gamma = 1.0$, V = 5000 ft/sec and $T_A = 773°C$ to M = .25 at $\gamma = 1.5$, V = 1000 ft/sec, and $T_A = 3273°C$.

It is realized that such wide variations will not be seen under actual stabilized flow conditions. However, it is expected that actual Mach numbers will fall within the calculated envelope. It is seen, moreover, that fluctuations in any parameter can shift the Mach number by a considerable amount, and that resolution of the operational profile must be accomplished before a final selection of the geometry of the free-standing member can be made, if a minimum - drag, maximum strength probe is desired. It is likewise apparent that design of such a probe for accommodation of all parameters will be extremely unlikely, if not impossible. It is possible, however, to hypothesize a probe cross-section to operate within the envelope, which would exemplify desirable characteristics in a widely fluctuating flow field.

2. THE HYPOTHETICAL PROBE

a. General

It will be assumed, in this discussion, that:

1.) Maximum temperature = 3000°C

2.) Maximum velocity = 5000 ft/sec

3.) $\frac{Cp}{Cv} = 1.4$ (approximately)

This set of parameters yields a Mach regime from about M = .9 to M = 1.5 as the absolute temperature changes from about 1273°C to 3273°C.

Since the flow may be expected, then, to fluctuate from subsonic to supersonic, the character of the reaction of a member immersed in both subsonic and supersonic flow must be considered. First,

a. General Cont...

the nature of the mathematical equations used to estimate coefficients of process will change from elliptical at subsonic flow, to parabolic at supersonic flow, which changes the $(M^2 - 1)^{1/2}$ term of such equations from imaginary to real. This represents a fundamental change in flow pattern, which says that, at supersonic velocities, no warning of the presence of a solid body is transmitted ahead of the body.

It can be shown that, in accordance with Ackeret's first order theory, drag and increase of drag with incidence retain the same sign as at subsonic speeds. However, the angle of

b. Supersonic Flow

It can be further shown that the single or double wedge is a desirable cross sectional shape for immersion in a supersonic flow, when minimum drag is a primary consideration, although such a shape, examined under two-dimensional theory, exhibits undersirable lift characteristics. Since design requirements need not be concerned with lift, a shape exhibiting low drag and poor lift under both subsonic and supersonic flow is indicated. A properly designed wedge or double wedge may satisfy these conditions.

(1.) Double Wedge (Rhombus)

It is assumed for purposes of discussion that streamlines in the flow can be represented with a set of parallel, equidistant lines. These lines will be deviated until they are parallel to the entering surfaces of the rhombus by the attached shock. The flow continues parallel to each surface until it arrives at the beginning of the expansion around the point of maximum thickness. As the flow goes through the expansion, it is swung around the corner, increasing speed and decreasing pressure until the Mach angle in the faster flow on the rear surface is attained. The expansion then ceases, and the flow continues parallel until the compression shock at the trailing edge is reached.

(1.) Double Wedge (Rhombus) Cont...

The flow is then turned parallel with the original undisturbed streamlines. This process obtains for both sides of the rhombus, and the flow from both sides joins without discontinuity. This does not mean, however, that forces cancel and zero drag results. To the contrary, the radiation of pressure waves requires energy, and shows up as wave drag.

(2.) Single Wedge

The general arguments applicable to the symmetrical double wedge apply as well to the single wedge, under first order Ackeret theory. In the case where a bluff trailing edge is employed in the single wedge, a friction wake develops. The absolute pressure over the bluff base can not be calculated because of breakaway of flow, but it has been measured. These values have been used, then, in calculating drag coefficients for various thickness to chord (t/c) ratios which indicate that the single wedge offers an advantage over the double wedge for ratios over 12%. Ratios of absolute base pressure to free stream static pressure in the order of 1/3 have been measured in wind tunnel tests at Mach numbers near 1.5. It can also be shown that, even with a vacuum on the base of a single wedge, the critical ratio is only 20%, above which a considerable advantage in reduction of drag, as compared with the double wedge, is realized.

3. A sketch, showing pictorially the various conditions discussed above, is presented in Figure 2.

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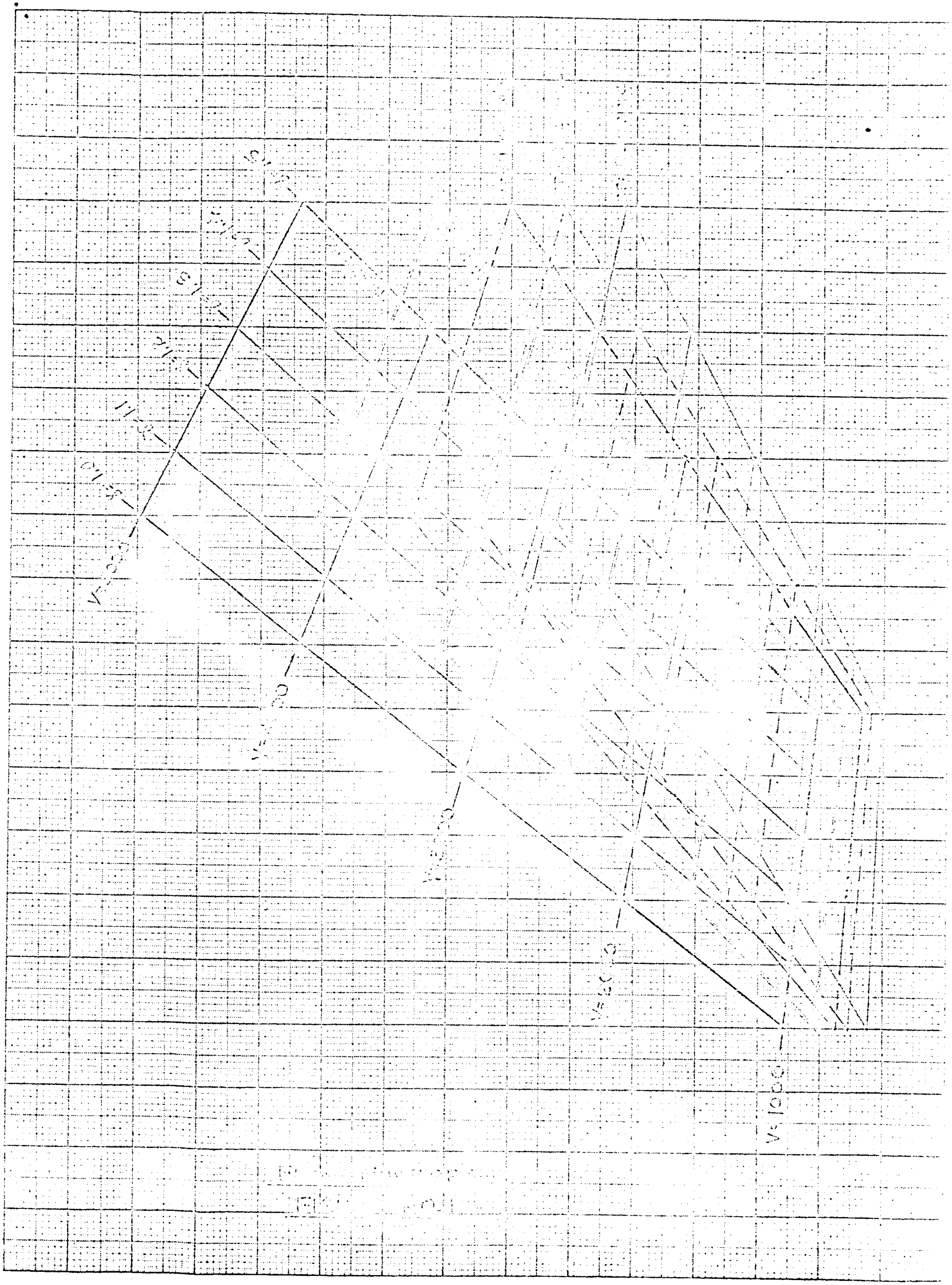
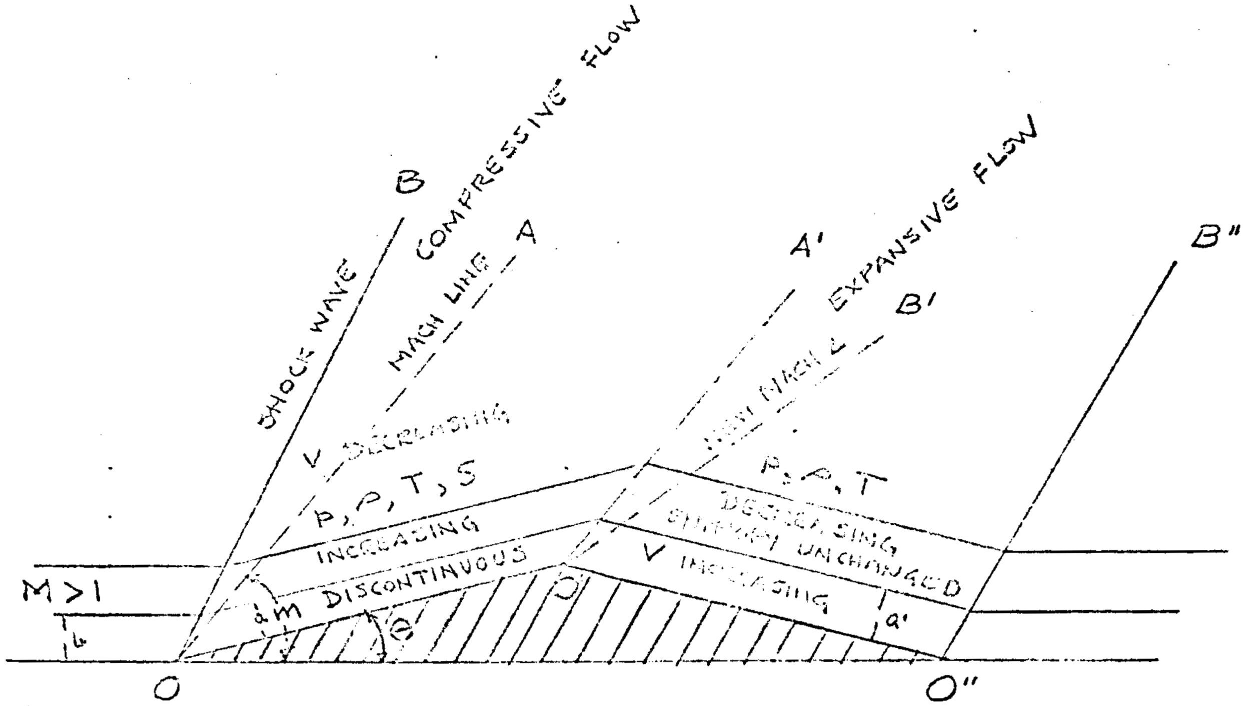
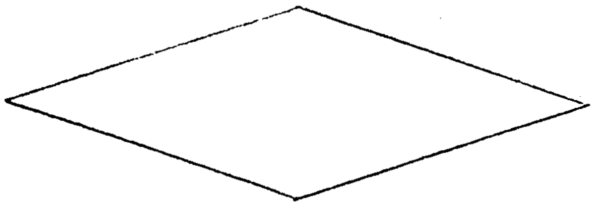


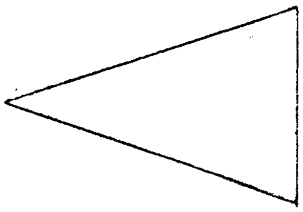


RHOMBUS IN SUPERSONIC FLOW

FIGURE NO. 2



DOUBLE WEDGE (RHOMBUS)



SINGLE WEDGE

BICONVEX

POSSIBLE TWO-DIMENSIONAL SHAPES

FIGURE NO. 3